

## Shear Modulus Profile Measurement of the Shallow-Water Seabed in Japan

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**SYNOPSIS** In a method of bottom shear modulus profiler (BSMP), the seabed admittance, that is defined as the ratio of the wave-induced particle motion to the wave pressure on the seafloor, is measured. The data are then used as input to a linear inversion scheme for calculation of the shear modulus profile. It was used to measure the seabed shear modulus of several locations in Japan. Results are compared to the values obtained at the same sites by the Standard Penetration Test (SPT) using the empirical formula of  $G = aN^b$  with  $a = 11.9$  and  $b = 0.8$ , where  $G$  is the shear modulus in MPa and  $N$  is the number of blow counts. The agreement between the results with BSMP and SPT is very good except at few locations, where the coherence between the pressure and the acceleration signals is low. It is expected that the results at these locations will be improved by increasing the measurement time.

### INTRODUCTION

The utilization of oceans without destroying the environment is an important subject especially for countries surrounded by water like Japan. As the construction of large-scale offshore and coastal structures increases, the selection of site becomes a very important factor. There are several conventional methods for a seabed property measurement, such as boring, the Standard Penetration Test (henceforth SPT), acoustic test and elastic wave test. However, due to the necessity of a platform or the difficulty of analysis, those methods consume time and cost.

On the other hand, a method presented in this paper is based on a totally different concept. The method is called the Bottom Shear Modulus Profiler (henceforth BSMP). The most significant difference from other methods is that the measurement can be done without disturbing the sediment structure. In addition, because BSMP uses wave-induced gravity water wave for the source of excitation, no external excitation source is necessary. In this paper, experimental results by the use of BSMP at several locations in Japan are reported.

### THE BACKGROUND OF BSMP

The method of BSMP was originally introduced by Yamamoto et. al. (1986) and its performance has been demonstrated since then through various field experiments (Suzuki et. al., 1990 and Trevorrow et. al. 1988, 1990). The principle

of the BSMP method is based on the theory of wave-seabed interaction. It is possible to determine the relationship between surface wave and seabed motion if the shear modulus profile and the water depth are given (Yamamoto 1983). Inversely, the shear modulus can be extracted by the wave pressure and seabed motion. The wave propagation model is so simple that the uniqueness and consistency of the solution is assured (Yamamoto et. al., 1986).

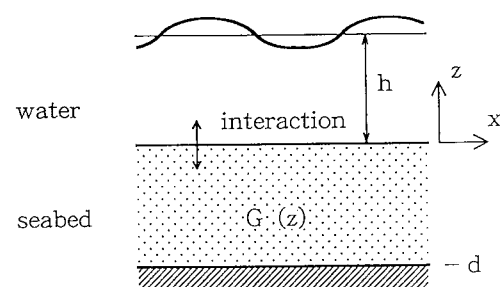


Fig.1 Wave propagation model

The wave propagation model for BSMP is shown in Fig. 1. The water depth  $h$  is constant above the sediment layer with the shear modulus profile  $G(z)$  that is constant in the  $x$  direction. Beneath the sediment layer, the boundary condition is assumed as an elastic halfspace with a constant shear modulus  $G(-d)$  or an ideally rigid boundary. In addition, several assumptions listed below are used.

- (i) The coupling of the solid frame and pore water is perfect.
- (ii) Shear deformation is dominant.
- (iii) Inertia force is negligible.
- (iv) Seabed deformation is linear.

These assumptions are used in determination of the complex matrix that describes the relationship between the seabed motion and the bottom water pressure.

FIELD EXPERIMENT

Several field experiments have been done in the past and confirmed the applicability of the BSMP method to the sandy deposits and carbonate sediment (Trevorrow et. al., 1988, 1990) and to soft clay and loose sand (Badiy, M. et. al. 1990). The experimental sites for this paper are (1) Tsurumi bridge, (2) Offshore Itsukaichi, (3) Shimizu Bay, (4) Offshore Urayasu and (5) The port of Kawasaki. The summary of the experiment conditions is shown in Table I. These experiments were conducted on normal weather conditions.

TABLE I  
Experiment condition.

Site	Depth	Time measured
Tsurumi*	14.0m	53min
Itsukaichi**	10.0m	unknown
Shimizu***	21.0m	86min
Urayasu*	11.5m	33min
Kawasaki*	14.8m	unknown

\* Tokyo Bay  
\*\* Hiroshima Prefecture  
\*\*\* Shizuoka Prefecture

The detailed description on the BSMP hardware and the experimental procedure are avoided since they have been presented in several papers (Trevorrow et. al., 1988, 1990, Badiy, M. et. al. 1990).

EXPERIMENTAL RESULTS

Figures 2 to 4 show the results of admittance, coherence function and shear modulus profile obtained from the experiment at Tsurumi bridge. Figures 5 to 7 show the results from the experiment offshore Itukaichi. Figures 8 to 10 show the results from the experiment at Shimizu Bay. Figures 11 to 13 show the result from the experiment offshore Urayasu. Figures 14 to 16 show the result from the experiment at the port of Kawasaki.

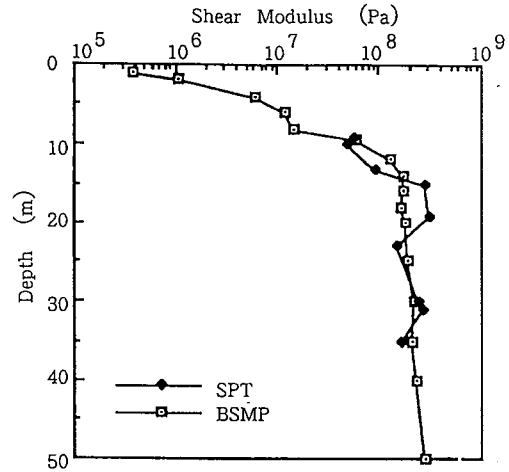


Fig. 2 Shear modulus profile at Tsurumi bridge

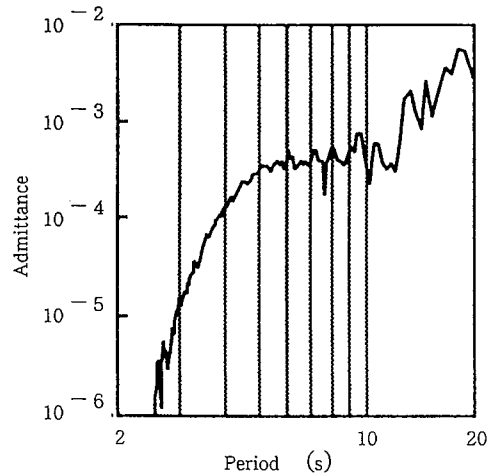


Fig.3 Admittance at Tsurumi bridge

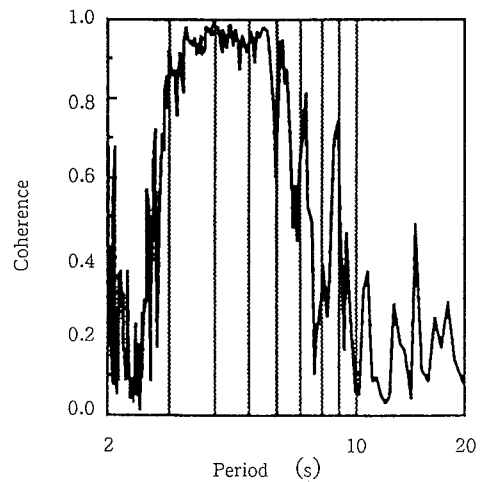


Fig. 4 Coherence at Tsurumi bridge

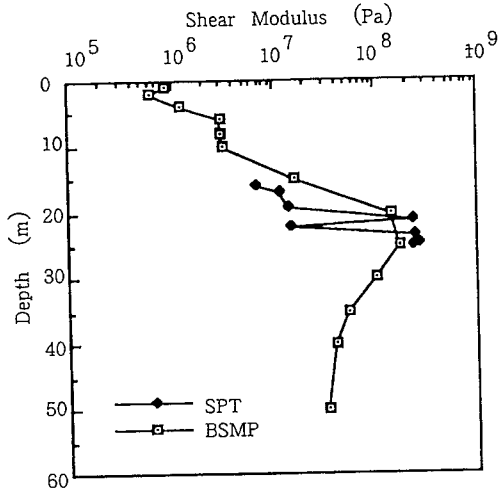


Fig. 5 Shear modulus profile offshore Itsukaichi

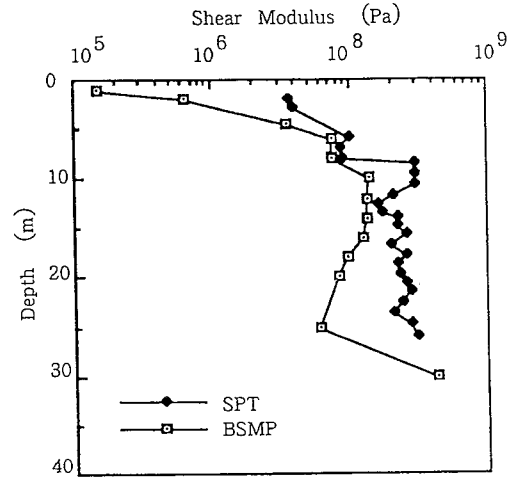


Fig. 8 Shear modulus profile at Shimizu Bay

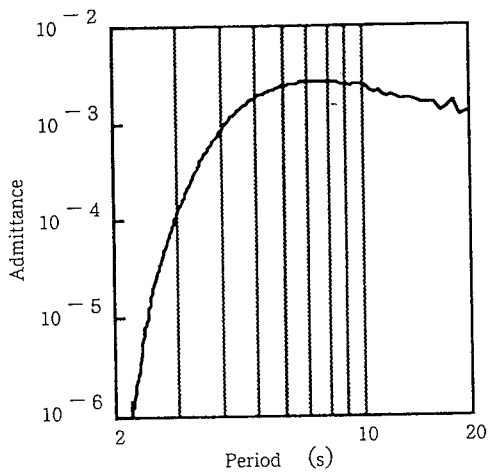


Fig. 6 Admittance offshore Itsukaichi

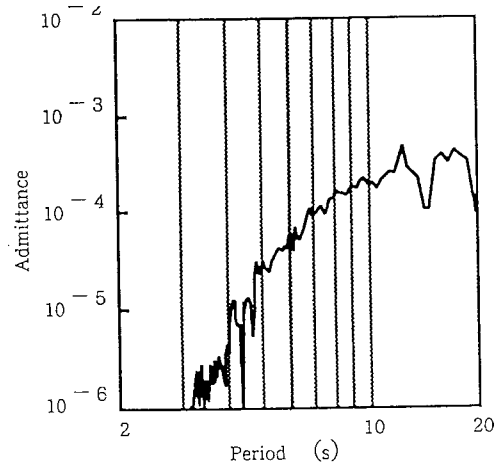


Fig. 9 Admittance at Shimizu Bay

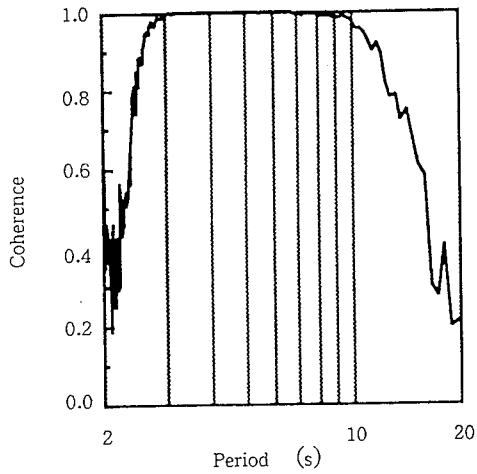


Fig. 7 Coherence offshore Itsukaichi

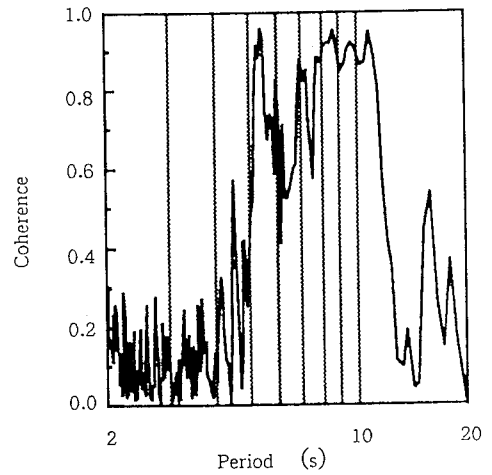


Fig. 10 Coherence at Shimizu Bay

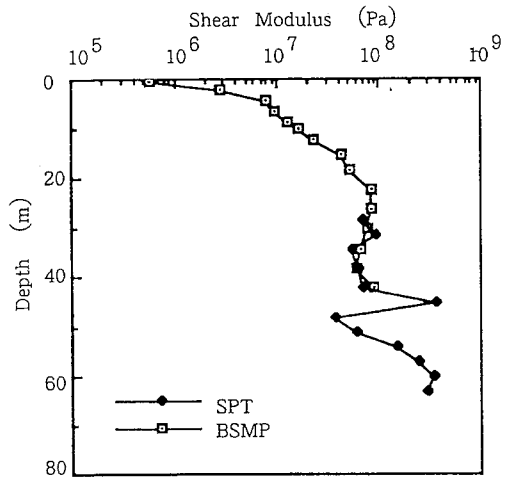


Fig. 11 Shear modulus profile offshore Urayasu

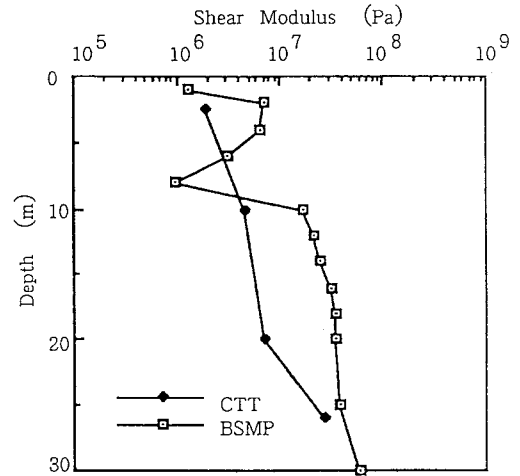


Fig. 14 Shear modulus profile at the port of Kawasaki

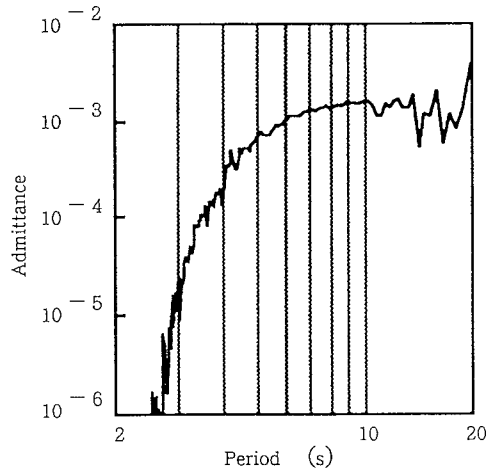


Fig. 12 Admittance offshore Urayasu

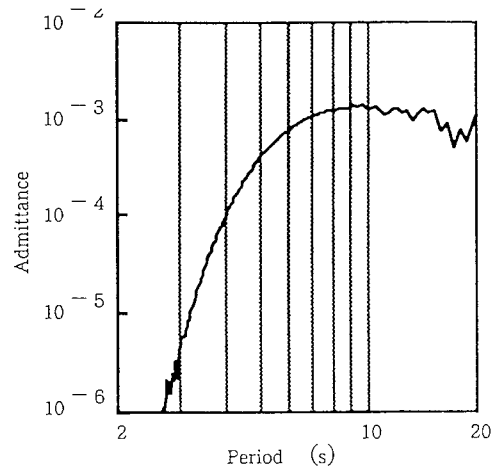


Fig. 15 Admittance at the port of Kawasaki

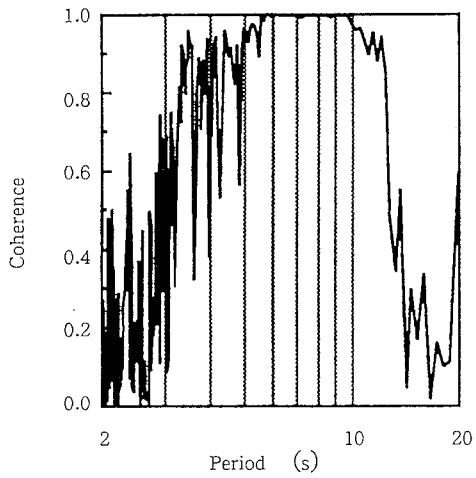


Fig. 13 Coherence offshore Urayasu

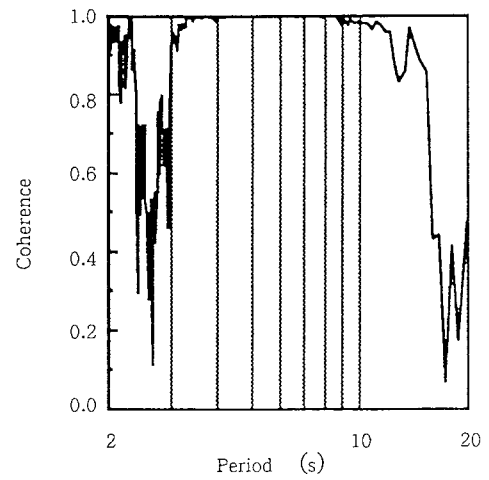


Fig. 16 Coherence at the port of Kawasaki

## DISCUSSION.

The admittance data obtained at five locations show clear differences to each other. By the magnitude of the admittance, the hardness of the seabottom is roughly estimated. The accuracy of the shear modulus profile calculated by the BSMP method depends on the quality of the measured data. The criteria for high quality data is (a) high coherence between pressure and acceleration data, and (b) reliable admittance data with a broad frequency band. The experimental results are examined based on these criteria.

(1) At Tsurumi bridge: Figure 2 shows good agreement of the shear modulus profiles from BSMP and SPT although the coherence larger than 6 Hz is not very good as shown in Fig. 4.

(2) Offshore Itsukaichi: The coherence data in Fig. 7 is reasonably high for the period from 3 to 10 seconds. But because of the irregularity in SPT data in Fig. 5 quantitative comparison becomes vague.

(3) At Shimizu Bay: The agreement of shear moduli in Fig. 8 is not good below 10m depth. The rough curve in admittance data due to the poor coherence seems to be responsible for it.

(4) Offshore Urayasu: Figure 11 shows good agreement at the layer where the BSMP and SPT data are overlapped.

(5) At the port of Kawasaki: The high coherence data is recognized from 3 to 10 seconds in Fig. 16. The admittance data is smooth in that period range. In spite of good quality data, the agreement deeper than 10m is poor.

These results basically support the criteria. In addition, the data with a relatively low coherence like at Tsurumi can produce a good result, if high coherent data are chosen among them. But considerably bad data like at Shimizu Bay must not be used for the inversion calculation. The case of Kawasaki harbor could be a special one, since the high coherent data did not produce a good result. The complicated geometry shown in Fig. 17 can be the reason for it. Because the experimental site is between the island and the breakwater, the theoretical model may not be applicable due to the reflection from the breakwaters and the island. In order to avoid this kind of problem, it seems necessary to check the BSMP and SPT results at at least one location if the area is narrow and surrounded by reflective walls.

## CONCLUSIONS

The following conclusions are drawn from the experiments.

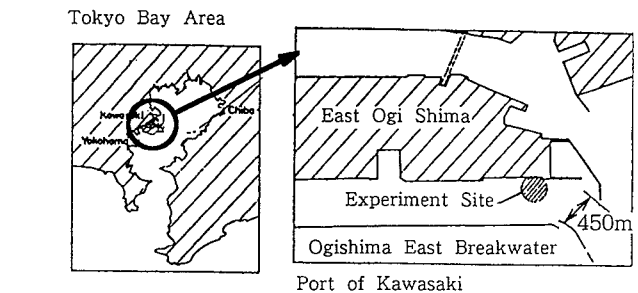


Fig. 17 Experimental site at the port of Kawasaki

- (i) The admittance data clearly shows its dependence on the hardness of the layer.
- (ii) The assumptions used in the seabed model are mostly satisfied if the area is open.
- (iii) The agreement between the BSMP and SPT result is good for most of the cases if the coherence between the pressure and acceleration signals is high.
- (iv) There are few cases with poor agreement between BSMP and SPT results even if the coherence is high.
- (v) If the measurement location is in a confined area, it is necessary to check the agreement between BSMP and SPT results at one or few locations to assure the validity of the BSMP model in that area.
- (vi) With a longer measurement time, the measurement accuracy of the admittance can be improved.

One and main advantage of the BSMP is that it can be used in deep water as well as in shallow water. Measurements at locations with water depths of more than fifty meters will be conducted in the near future.

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